CLAIMS

What is claimed is:

1. A method for locating a fracture in an earth formation using a propagation tool disposed in a borehole traversing the formation, the tool having a longitudinal axis, comprising:
   (a) transmitting electromagnetic energy from a transmitter antenna disposed on the propagation tool with its magnetic moment at an angle with respect to the longitudinal tool axis;
   (b) measuring voltage signals detected at a plurality of receiver antennas disposed on the propagation tool with their axes at an angle with respect to the longitudinal tool axis and oriented in different directions from one another, the voltage signals being related to the transmitted electromagnetic energy;
   (c) associating the measured voltage signals with a plurality of azimuthal angles; and
   (d) shifting at least one of the measured voltage signals by a predetermined angle and processing the shifted and unshifted signals to locate the fracture.

2. The method of claim 1, wherein the measured voltage signals relate to a phase difference or a magnitude ratio of the signals detected by said receiver antennas.

3. The method of claim 2, wherein step (d) includes determining signal harmonics from the measured voltage signals.

4. The method of claim 3, wherein step (d) includes performing a subtraction or addition between the shifted and unshifted signals.

5. The method of claim 4, wherein step (d) includes shifting at least one of the measured signals by 90 degrees.

6. The method of claim 4, wherein the transmitter antenna is disposed on the tool with its

magnetic moment oriented in a transverse plane with respect to the longitudinal tool axis.

7. The method of claim 4, wherein a first pair of receiver antennas are disposed on the tool with their axes projected in a transverse plane with respect to the longitudinal tool axis and orientated in different directions from one another.

8. The method of claim 7, wherein the transmitter antenna is disposed on the tool with its magnetic moment oriented in a transverse plane with respect to the longitudinal tool axis.

9. The method of claim 8, wherein step (d) includes determining an orientation of the fracture relative to an axis of an antenna disposed on the tool.

10. The method of claim 9, wherein step (d) includes shifting at least one of the measured signals by 90 degrees.

11. The method of claim 8, wherein the tool comprises a second transmitter antenna disposed thereon with its magnetic moment oriented at an angle with respect to the longitudinal tool axis and perpendicular to the magnetic moment of the first transmitter antenna.

12. The method of claim 11, wherein step (b) comprises measuring the voltage signals corresponding to the electromagnetic energy transmitted from the first and second transmitter antennas at the first pair of receiver antennas.

13. The method of claim 12, wherein step (d) includes determining an orientation of the fracture relative to an axis of an antenna disposed on the tool.

14. The method of claim 11, wherein a second pair of receiver antennas are disposed on the tool with their axes projected in a transverse plane with respect to the longitudinal tool axis and oriented in different directions from one another.

15. The method of claim 14, wherein step (b) comprises measuring the voltage signals corresponding to the electromagnetic energy transmitted from the first and second transmitter antennas at the first and second pair of receiver antennas.

16. The method of claim 4, wherein step (b) comprises measuring a voltage signal detected at a receiver antenna disposed on the tool with its axis parallel to and substantially aligned with the magnetic moment of the transmitter antenna.

17. The method of claim 16, wherein the parallel and aligned transmitter and receiver antennas are oriented in an X-coordinate direction or in a Y-coordinate direction.

18. The method of claim 17, wherein step (d) includes determining an orientation of the fracture relative to an axis of an antenna disposed on the tool.

19. A system for locating a fracture in an earth formation comprising:

a propagation tool having a longitudinal axis and adapted for disposal within a borehole traversing the formation;

a transmitter antenna disposed on the tool with its magnetic moment at an angle with respect to the tool axis;

a plurality of receiver antennas disposed on the tool with their axes at an angle with respect to the tool axis and oriented in different directions from one another, the antennas adapted to detect voltage signals associated with electromagnetic energy transmitted by the transmitter antenna;

processing means to measure the voltage signals detected by said receiver antennas;

processing means to associate the measured voltage signals with a plurality of azimuthal angles; and

processing means to shift at least one of the measured voltage signals by a predetermined angle and to process the shifted and unshifted signals to locate the

fracture.

20. The system of claim 19, wherein the processing means to measure the detected voltage signals comprises means to measure a phase difference or a magnitude ratio of the detected voltage signals.

21. The system of claim 20, wherein the processing means to measure the detected voltage signals further comprises means to determine signal harmonics from the detected voltage signals.

22. The system of claim 21, wherein the processing means to process the shifted and unshifted signals comprises means to perform a subtraction or addition between the shifted and unshifted signals.

23. The system of claim 22, wherein the processing means to shift at least one of the measured signals comprises means to shift at least one of the measured signals by 90 degrees.

24. The system of claim 22, wherein the transmitter antenna is disposed on the tool with its magnetic moment oriented in a transverse plane with respect to the longitudinal tool axis.

25. The system of claim 22, the tool comprising a first pair of receiver antennas disposed thereon with their axes projected in a transverse plane with respect to the tool axis and orientated in different directions from one another.

26. The system of claim 25, wherein the transmitter antenna is disposed on the tool with its magnetic moment oriented in a transverse plane with respect to the longitudinal tool axis.

27. The system of claim 26, the tool comprising a second transmitter antenna disposed thereon with its magnetic moment oriented at an angle with respect to the tool axis and perpendicular to the magnetic moment of the first transmitter antenna.

28. The system of claim 27, the tool comprising a second pair of receiver antennas disposed thereon with their axes projected in a transverse plane with respect to the tool axis and oriented in different directions from one another.

29. The system of claim 28, wherein the processing means to process the shifted and unshifted signals comprises means to determine an orientation of the fracture relative to an axis of an antenna disposed on the tool.

30. The system of claim 22, the tool comprising a receiver antenna disposed thereon with its axis parallel to and substantially aligned with the magnetic moment of the transmitter antenna.

31. The system of claim 31, wherein the parallel and aligned transmitter and receiver antennas are oriented in an X-coordinate direction or in a Y-coordinate direction.

32. A method for locating a fracture in an earth formation penetrated by a borehole, comprising:

(a) moving a propagation tool in the borehole, the tool having a longitudinal axis and including a first transmitter antenna disposed thereon with its magnetic moment at a right angle to the tool axis and a plurality of receiver antennas disposed thereon with their axes at right angles to the tool axis;

(b) transmitting electromagnetic energy using the first transmitter antenna;

(c) measuring voltage signals detected at the plurality of receiver antennas, the signals being related to the transmitted electromagnetic energy;

(d) associating the measured signals with a plurality of azimuthal angles;

(e) shifting at least one of the measured signals by a predetermined angle; and

(f) locating the fracture using the shifted and unshifted signals.

33. The method of claim 32, wherein step (c) includes measuring a phase difference or a magnitude ratio of the voltage signals detected at a first pair of receiver antennas disposed on the tool with their axes at right angles to one another.

34. The method of claim 33, wherein step (e) includes shifting at least one of the measured signals by 90 degrees and respectively adding or subtracting the shifted signal to or from an unshifted signal.

35. The method of claim 34, wherein step (f) includes determining an orientation of the fracture relative to an axis of an antenna disposed on the tool.

36. The method of claim 35, wherein step (c) includes measuring the voltage signals corresponding to electromagnetic energy transmitted from the first transmitter antenna and from a second transmitter antenna disposed on the tool with its magnetic moment at an angle with respect to the tool axis and perpendicular to the magnetic moment of the first transmitter antenna.

37. The method of claim 36, wherein step (c) includes measuring the voltage signals corresponding to electromagnetic energy transmitted from the first and second transmitter antennas at the first pair of receiver antennas and at a second pair of receiver antennas disposed on the tool with their axes at right angles to one another.

38. The method of claim 35, wherein step (c) includes measuring a voltage signal detected at a receiver antenna oriented in an X-coordinate direction or in a Y-coordinate direction, the measured signal corresponding to electromagnetic energy transmitted from the first transmitter antenna oriented in the same respective direction.

39. A method for locating a fracture in an earth formation using a logging tool disposed in a borehole traversing the formation, the tool having a longitudinal axis, comprising:

(a) transmitting electromagnetic energy from a transmitter antenna disposed on the

tool with its magnetic moment at an angle with respect to the longitudinal tool axis;

(b) measuring voltage signals detected with a receiver antenna disposed on the tool with its axis at an angle with respect to the longitudinal tool axis, the voltage signals being related to the transmitted electromagnetic energy;

(c) determining a second harmonic associated with the measured voltage signals; and

(d) performing a calculation on the second harmonic to locate the fracture.

40. The method of claim 39, wherein step (d) includes averaging values computed from real and imaginary parts of the second harmonic.

41. The method of claim 40, wherein step (d) includes calculating the following equation:

$$\phi_{frac}(f,t,r) = \frac{1}{4}\left(\tan^{-1}\frac{b_{RE2}}{a_{RE2}} + \tan^{-1}\frac{b_{IM2}}{a_{IM2}} \right),$$

where

(f, t, r) corresponds to a voltage signal measurement at frequency f, transmitter antenna t, and receiver antenna r;

ϕ is the angle of the fracture relative to an axis of the measurement antenna; and

a_{RE2}, b_{RE2}, a_{IM2}, b_{IM2} are coefficients corresponding to real and imaginary parts of the second harmonic.

42. The method of claim 40, wherein the transmitter and receiver antennas are disposed on the tool with their axes parallel to one another and oriented in a transverse plane with respect to the longitudinal tool axis.

43. The method of claim 39, wherein step (b) comprises measuring voltage signals detected with a plurality of receiver antennas disposed on the tool each with its axis at an angle with respect to the longitudinal tool axis.

44. The method of claim 43, wherein step (d) includes averaging values computed from real

and imaginary parts of the second harmonic.

45. The method of claim 44, wherein step (d) includes calculating the following equation:

$$\phi_{frac}(f,t,ri) = \frac{1}{4}\left(\tan^{-1}\frac{b_{RE2}}{a_{RE2}} + \tan^{-1}\frac{b_{IM2}}{a_{IM2}}\right)$$

where

(f, t, ri) corresponds to a voltage signal measurement at frequency f, transmitter antenna t, and receiver antenna ri;

ϕ is the angle of the fracture relative to an axis of the measurement antenna; and

a_{RE2}, b_{RE2}, a_{IM2}, b_{IM2} are coefficients corresponding to real and imaginary parts of the second harmonic.

46. The method of claim 45, wherein step (d) includes calculating the following equation:

$$\frac{1}{N_{rec}}\sum_{i=1}^{Nrec}\phi_{frac}(f,t,ri)$$

where (f, t, ri) corresponds to a measurement at the ith receiver antenna and N_{rec} is the number of receiver antennas.

47. The method of claim 43, wherein the transmitter and receiver antennas are disposed on the tool with their axes parallel to one another and oriented in a transverse plane with respect to the longitudinal tool axis.

48. A system for locating a fracture in an earth formation comprising:

a logging tool having a longitudinal axis and adapted for disposal within a borehole traversing the formation;

a transmitter antenna disposed on the tool with its magnetic moment at an angle with respect to the tool axis;

a receiver antenna disposed on the tool with its axis at an angle with respect to the

tool axis, the antenna adapted to detect voltage signals associated with electromagnetic energy transmitted by the transmitter antenna;

processing means to determine a second harmonic associated with voltage signals detected with the receiver antenna; and

processing means to perform a calculation on the second harmonic to locate the fracture.

49. The system of claim 48, wherein the processing means to perform a calculation on the second harmonic comprises means to average values computed from real and imaginary parts of the second harmonic.

50. The system of claim 49, wherein the processing means to perform a calculation on the second harmonic comprises means to calculate the following equation:

$$\phi_{frac}(f,t,r) = \frac{1}{4}\left(\tan^{-1}\frac{b_{RE2}}{a_{RE2}} + \tan^{-1}\frac{b_{IM2}}{a_{IM2}} \right)$$

where

(f, t, r) corresponds to a voltage signal measurement at frequency f, transmitter antenna t, and receiver antenna r;

ϕ is the angle of the fracture relative to an axis of the measurement antenna; and

a_{RE2}, b_{RE2}, a_{IM2}, b_{IM2} are coefficients corresponding to real and imaginary parts of the second harmonic.

51. The system of claim 48, wherein the transmitter and receiver antennas are disposed on the tool with their axes parallel to one another and oriented in a transverse plane with respect to the longitudinal tool axis.

52. The system of claim 48, further comprising a second receiver antenna disposed on the tool with its axis at an angle with respect to the tool axis and said processing means adapted to determine the second harmonic using the voltage signals detected with said

receiver antennas.

53. The system of claim 52, wherein the processing means to perform a calculation on the second harmonic comprises means to average real and imaginary parts of the second harmonic.

54. The system of claim 53, wherein the processing means to perform a calculation on the second harmonic comprises means to calculate the following equation:

$$\phi_{frac}(f,t,ri) = \frac{1}{4}\left(\tan^{-1}\frac{b_{RE2}}{a_{RE2}} + \tan^{-1}\frac{b_{IM2}}{a_{IM2}}\right)$$

where

(f, t, ri) corresponds to a voltage signal measurement at frequency f, transmitter antenna t, and receiver antenna ri;

ϕ is the angle of the fracture relative to an axis of the measurement antenna; and

a_{RE2}, b_{RE2}, a_{IM2}, b_{IM2} are coefficients corresponding to real and imaginary parts of the second harmonic.

55. The system of claim 54, wherein the processing means to perform a calculation on the second harmonic comprises means to calculate the following equation:

$$\frac{1}{N_{rec}}\sum_{i=1}^{Nrec}\phi_{frac}(f,t,ri)$$

where (f, t, ri) corresponds to a measurement at the ith receiver antenna and N_{rec} is the number of receiver antennas.

56. The system of claim 52, wherein the transmitter and receiver antennas are disposed on the tool with their axes parallel to one another and oriented in a transverse plane with respect to the longitudinal tool axis.